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ABSTRACT. The paper considers the question of climatology of noctilucent clouds (geometry, time-space characteristics, geographical, geliophysical and interplanetary conditions connected with cloud appearance), their physical nature (physical-chemical characteristics and optical properties of particles, their concentration and the brightness of noctilucent clouds) and the height, kinematic characteristics and dynamics of the noctilucent cloud field. The paper describes the activity of the World Special Geophysical Center on Noctilucent Clouds, organized in 1964 in Tartu.

Interest in the study of noctilucent clouds increases from year to year. /11 * This is witnessed by the increase in the volume and scope of works in this investigative field both here in the Soviet Union and abroad. Thus, for example, during the last two or three years direct investigations of noctilucent clouds have been made using rockets and laser sounding of cloud fields, a widespread network of stations has been organized for patrolling for noctilucent clouds in the northern and southern hemispheres, etc.

All this is tied in with the fact that the essence of the problem of noctilucent clouds encompasses not only studies of the nature and origin of this phenomenon as a natural object; noctilucent clouds are at the same time a good informational source for data on the dynamics (wave motions and turbulence) of the upper layers of the atmosphere, especially the mesopause. In addition, noctilucent clouds represent a subject whose study may yield us valuable data on the physics of the mesopause and perhaps the mesophere and the thermosphere as a whole. Investigations of noctilucent clouds have established many facts which must find a true explanation on the basis of assumptions concerning the nature and origin of this interesting phenomenon and on the physical processes related to it. Such facts are: the relative rarity of appearances, the almost constant altitude, the relatively low width of the distribution area, the appearance basically only in the summer, the fact that they are observed only at definite negative heights of the sun, the multiform, thin structure and the heavy wave and vortex motion in the cloud field, etc.

However, in spite of a few significant successes in recent years concerning this study of the nature and determination of the time-space characteristics and kinematic parameters of these clouds, the problem of noctilucent clouds has until this time remained decisively unresolved. Thus, for example, the physical-chemical nature of the particles forming the noctilucent clouds is only partially known. The origin of these particles (whether they are terrestrial, local or interplanetary products) has yet to be definitely established. We know even less concerning the mechanism of the formation and climatology of this

*Numbers in the margin indicate pagination in the foreign text.

unique form of atmospheric aerosols. The general climatology of noctilucent clouds includes the following questions: (a) the geometry and time-space characteristics of the appearance of noctilucent clouds; and (b) the geophysical and perhaps also helio-physical and meteoric-commentary, i.e. interplanetary, conditions for the appearance of noctilucent clouds.

The first question encompasses geometry, the determination of the altitude and spatial positioning as well as the duration time and true frequency of appearance of this phenomenon. The second question is the study /12
of the geophysical, helio-physical and interplanetary conditions before, during and after the appearance of noctilucent clouds, i.e. the determination of the correlation between the appearances of noctilucent clouds and, for example, solar activity, meteor flows, the conditions of the ionospheric layers, the temperature regime in the mesopause, the synoptic condition in the lower atmosphere, etc.

In view of the fact that as natural phenomena noctilucent clouds have a common global character, the solution of these problems outlined demands the organization of systematic observations of noctilucent clouds according to a single common program over an intelligently planned network of stations on an international scale. In all probability, the problems presented might also be solved with the aid of properly equipped artificial earth satellites flying a polar orbit over a sufficiently long time period (no less than one year). However, this last question requires additional study.

Geometry. The conditions of the visibility of noctilucent clouds are related to their geometry: they appear visible only during a certain period of twilight, specifically during the so-called navigational twilight, although sometimes also during the brighter civil twilight and the less bright astronomical twilight. In view of the fact that the absolute time for the onset of the various phases of twilight throughout the year varies, the time period permitting the visibility of noctilucent clouds fluctuate depending on the season. Noctilucent clouds are often unseen from those points over which they suddenly spread. They can be successfully observed only from stations located hundreds of kilometers from the points where the clouds take form. In addition, one and the same cloud may be noted from many mutually distant stations, which substantially hinders the identification of observations relating to one and the same object.

These and other similar problems demand the study of the geometry of noctilucent clouds; otherwise it will be impossible to create a picture of their true distribution in time and space as well as clarify the dependences existing between the appearance of this atmospheric phenomenon and the various factors of a geographic, geomagnetic, geophysical and space character. In addition, there are several extreme cases when it would seem that noctilucent clouds should not be visible but have actually been observed. Thus, for example, in 1958 at Pskov and in 1959 at Irgiz noctilucent clouds were observed when the sun had sunk to 1.7° and 1.2° respectively, and in 1957 at Tiksi Bay and in 1958 at Pskov it had reached 20.8° and 20.0° respectively [1]. In the first case rather dense clouds were noted which were still visible against the bright twilight background (at small angles of the sun's sinking) or were illuminated by light scattered by the upper layers of the atmosphere (when the sun had sunk deep). It is possible that this was a case of luminescence; the problem is not yet clear.

What has been stated shows how important is the question of the geometry of noctilucent clouds in the problem of the statistical and climatological study of this phenomenon.

The time-space characteristics of noctilucent clouds. The study of questions on the seasonal and geographical distribution of the phenomena of noctilucent clouds has many complications. These are based on the fact that, as has already been said earlier, as an object of investigation noctilucent clouds have a global character, as well as the fact that ground observations of noctilucent clouds depend greatly on the meteorological conditions of the troposphere. This latter fact permits us to determine only the visible and not the true distribution of appearances of noctilucent clouds, because their observations are distorted by various sources of samples and /13 mainly by the yearly and latitudinal behavior of the tropospheric cloud cover.

Until now we have had no general picture of the true distribution of the appearances of noctilucent clouds in time and in space. The observational material on hand permits us to solve this problem only partially.

Questions concerning the geographical and seasonal distribution of the appearances of noctilucent clouds over the territory of the USSR were studied on the basis of observations from stations in the USSR Hydrometeorological Service from 1957 to 1959 [1]. The solution of this problem on the scale of the entire planet still lies before us, so that below we have briefly set some goals in the handling of this problem.

As is well known, at the beginning of the International Year of the Quiet Sun, a rather dense network of observation stations for noctilucent clouds was organized over the territory of the USSR. Throughout this territory there were 206 stations on the USSR Hydrometeorological Service and 12 stations handled by the All-Union Astronomical and Geodesic Society. The network for these stations was created such that it would uniformly cover the entire portion of the Soviet territory over which noctilucent clouds might appear (Figure 1). The northern-most station was in Murmansk ($\phi = 68°58'$ N), the southern-most station was at Simferopol ($\phi = 45°01'$ N), the eastern-most station was at Anadyr' ($\lambda = 177°34'$ E) and the western-most was at Uzhgorod ($\lambda = 22°16'$ E). Thus a belt 23°57' wide and 155°18' long is encompassed by the patrol stations, which averages out to 8.4 stations per degree in latitude and 1.3 stations per degree in longitude. Considering on the one hand the geometrical conditions for the visibility of noctilucent clouds for one station and the total number of stations and their distribution on the other hand, we may safely say that under favorable meteorological conditions and conscientious observations, the probability of recording all the appearances of noctilucent clouds over the territory of the USSR is close to complete.

The patrol stations carry out observations from 1 March to 1 November. /14
The essence of the patrol observations is that during the medium and dark

phases of twilight the observer carefully scans the sky every 15 minutes with the object of establishing the presence or absence of noctilucent clouds and recording the state of the general cloud cover. The observations take place under all meteorological conditions. Until recent years, there was very little data on the appearance of noctilucent clouds in the Western Hemisphere. Recently Fogle organized a network of patrol stations across the territory of North America [2]. According to his data, in 1964 there were already 91 patrol stations participating throughout North America (Figure 2).

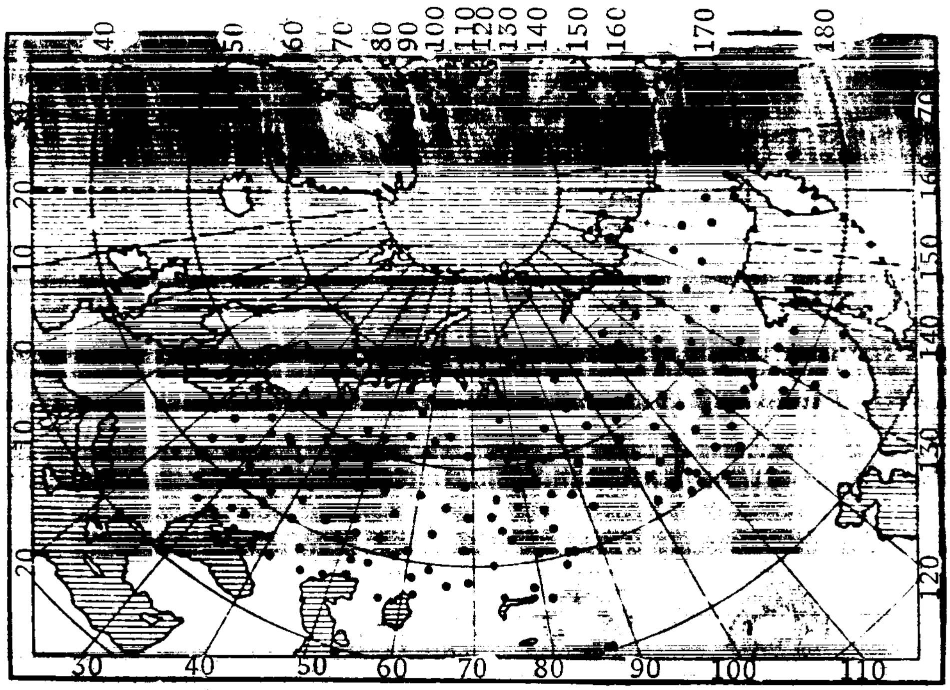

Figure 1. Distribution of Stations for Visual Patrolling of Noctilucent Clouds over the Territory of the USSR.

If we take into account the patrol stations which have been organized on the British Isles, in the Scandinavian countries and in Central Europe (the Polish People's Republic, the Czechoslovakian Soviet Republic and others), we may now speak in terms of the more or less systematic observation of noctilucent clouds in the Northern Hemisphere. In accordance with a single mutually agreed program of observations and the organized international exchange of observation data, such a network of stations will in the near future permit us to reach solutions in the questions of the time-space characteristics of the appearance of noctilucent clouds in the Northern Hemisphere.

What is especially interesting in terms of the study of the formation of noctilucent clouds is the question of whether or not the zone of appearance for such clouds is determined by geographic or geomagnetic latitudes. No less important is the question of the extent of the cloud fields. Thus, for example, on the night of 3/4 July 1959, noctilucent clouds were observed along the northern horizon for more than 180° in longitude (from $\lambda = 118°$ E to $\lambda = 63°$ W) [3]. The question of whether the object of observations was a single cloud which drifted with twilight from east to west or whether the earth's sphere had been covered with a belt of noctilucent clouds is of great interest.

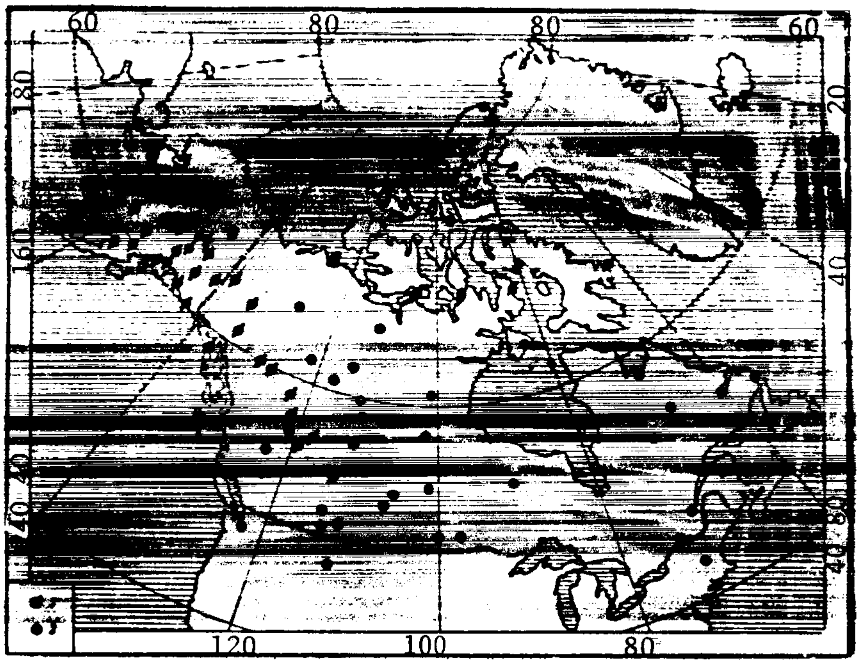

Figure 2. Distribution of Stations for the Observation of Noctilucent Clouds over the Territory of North America. 1 - Stations opened in 1963; 2 - Stations opened in 1964.

The situation in terms of the observation of noctilucent clouds in the Southern Hemisphere is substantially less promising. Heretofore there have been no published data on the observations of this phenomenon in the Southern Hemisphere and only recently have a few notes appeared. Because detailed material is quite scarce, we have dwelt upon these observations later in this article. /15

Work [4] describes two cases of observations of noctilucent clouds in the Antarctic and in Mirnyy by the members of a Czechoslovakian group in an Antarctic expedition. The first case relates to the appearance of 28 March 1958. A small (20×20°) field was observed 35° above the horizon. The direction of motion ran from the North-West to South-East and the velocity of motion for the field was around 98 m/sec. It is interesting to note that along with the noctilucent clouds, the aurora borealis was also observed above the northern horizon. In the second case in Mirnyy the noctilucent clouds were observed on 13 May 1959, when they appeared around the zenith region and slowly moved to the southwest.

In [5], Mrkos notes that in 1958 in the Antarctic he observed noctilucent clouds for several nights and that in color and morphological structure they were in no respect different from noctilucent clouds which he had observed in Europe. Mrkos had also conducted observations of noctilucent clouds from on board the expedition vessel in the Southern Hemisphere at a latitude of $\phi = 37°$ S. It is interesting to note also that according to the data offered by Mrkos, the noctilucent clouds in the Antarctic were observed in the form of radial belts emanating from a point located above the northern horizon.

In the work by Paton [3] there is also a note concerning the 1962 observations of noctilucent clouds by a certain Holman in the upper southern latitudes from on board a vessel.

In 1964 Fogle organized a network of patrol observations of noctilucent clouds in the Southern Hemisphere on the basis of local meteorological stations. According to his data, the stations totalled 53 (Figure 3) and encompassed the geographic zone between 45 and 90° S. The results of the observations from these stations have yet to be published.

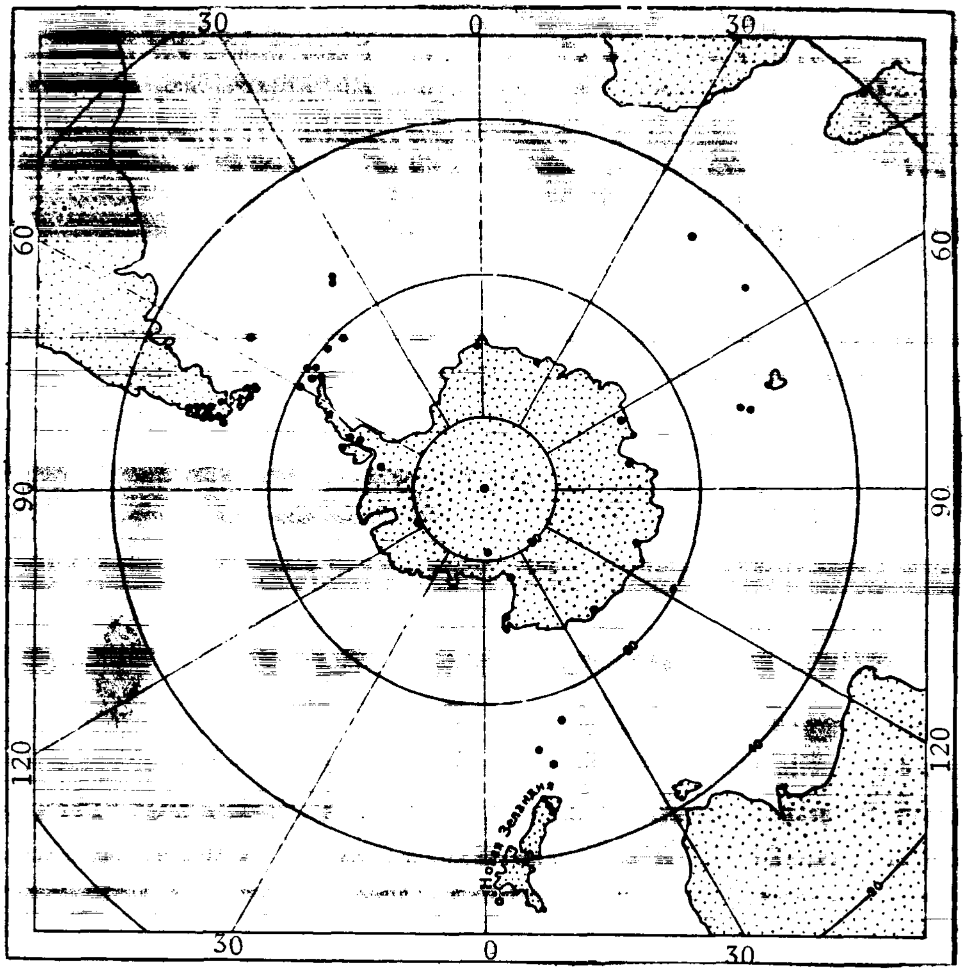

Figure 3. Distribution of Stations for Observing Noctilucent Clouds in the Southern Hemisphere.

In December of 1964 Fogle organized a special expedition in the Southern Hemisphere for observing noctilucent clouds. The observations were conducted for three months in Chile, at Punta-Arenas. In November of 1965 Fogle obtained a photograph of noctilucent clouds in the Southern Hemisphere (in Punta-Arenas).

Patrol observations in the Southern Hemisphere have to be developed as much as possible, both on land and aboard vessels cruising in the upper southern latitudes.

No less important for the climatology of noctilucent clouds are the time characteristics of their appearance. The general statistics on all available observational material indicate that the appearance of noctilucent clouds is limited to the summer season with its maximum in July (in the Northern Hemisphere). In addition, simultaneous examination of the distribution of noctilucent cloud appearances in time and space shows that the farther north we go, the later the date for the maximum number of these cloud observations. More detailed analysis of the time distribution of the appearances of such clouds is given in [1].

It appears to us that the winter appearance of noctilucent clouds is of special interest. At the moment we know of only two such cases.

On 27 January 1960 noctilucent clouds were observed over the northwestern horizon in Czechoslovakia ($\phi = 49.2°$ N and $\lambda = 20.2°$ E) [6]. Both visual and photoelectric observations were conducted.

On 15 February 1962 Lepp observed noctilucent clouds over the northern horizon in the Estonian SSR ($\phi = 58.8°$ N and $\lambda = 25.3°$ E) (for negative heights of the sun from 11°12' to 11°58') [7]. Eleven photographs were /16 obtained. The cases described show that in the future we will have to give serious attention to such phenomena inasmuch as heretofore it had been assumed that noctilucent clouds could appear only in the summer.

The geographic, helio-physical and interplanetary conditions related to the appearances of noctilucent clouds have as yet been almost entirely unstudied. In the literature, only the results of a few attempts to find a relationship between the appearances of noctilucent clouds and other phenomena in the atmosphere have been published. Thus, for example, there are several works by N. I. Grishin concerning the relationship between the appearances of noctilucent clouds and the motion of anticyclones in the troposphere [8-10]. In [11], Rosinski and Pierrard examined the question of the appearance of noctilucent clouds with respect to the clusters of micrometeors in the mesopause. There are also some data on the relationship of the appearances of noctilucent clouds to solar activity (for example, the work by Bezrukovaya, which is in press, and the work by Vasil'yev).

It is still hard to say which of these might be closer to the right track. However, it is quite clear that the mechanism for the formation of noctilucent clouds cannot be some sort of isolated process unrelated (directly or indirectly) to other phenomena in the atmosphere of our planet. And because /17 we still do not know the mechanism of the formation of these clouds, finding any correlation between the appearances the noctilucent clouds and helio-geophysical phenomena could be the key to solving this problem.

The physical nature of noctilucent clouds. By this we mean the physical and chemical characteristics and optical properties of the particles forming the noctilucent clouds as well as the concentration and volume density of particles in the cloud field as a whole and in its individual structural details, the absolute brilliance and the thickness of these details. Obviously, these data can be obtained through optical observations, rocket investigations within the cloud field and laser sounding.

The physical-chemical characteristics and optical properties of the particles. Valuable data on the nature of noctilucent clouds may be obtained from spectral investigations. Unfortunately, we have as yet obtained only a few very modest spectra. Störmer [12] first obtained the spectra of noctilucent clouds in 1932. According to his data, the spectra of the noctilucent clouds in no way differed clearly from the spectrum of the sky. In 1951 N.I. Grishen obtained several dozen spectra for noctilucent clouds within the range λ = 4000 - 6800 Å [13], according to which on the curve of the energy distribution along the spectrum six maxima were found: three very clearly in the blue portion (λ_1 = 4230 Å, λ_2 = 4480 Å, λ_3 = 4630 Å), two weak ones in the yellow-green portion (λ_4 = 5000 Å, λ_5 = 5300 Å) and a broad, intense maximum in the red section (λ_6 = 6500 Å), the increase in the brightness of the noctilucent clouds being accompanied by an increase in the maxima λ_2 and λ_6. However, it has been difficult to give a definitive answer to the possibility of photoluminescence in noctilucent clouds in terms of these spectra (this idea was first expressed as long ago as 1924 by I.I. Putilin [14]).

The spectra obtained by N.I. Grishen were also processed by Vestine and Deirmendjian [15]. They studied the behavior of the dispersive ability of the material constituting the noctilucent clouds along the spectra and with the light dispersion angle and arrived at these conclusions: a) the dispersive power of the particles forming the clouds is close to the Rayleigh law (λ^{-4}); and b) if we assume that these particles are dielectric spheres with a refractive index of m = 1.33, their radii equal $r \simeq 4 \cdot 10^{-5}$ cm.

According to the determination of the yellowness of the noctilucent clouds, V.V. Sharonov came to the same conclusion, specifically that the light diffusion by the material constituting these clouds occurs basically in accordance with Rayleigh's law [16].

A very important method for obtaining data on the nature of noctilucent clouds is the measurement of the polarization of the luminescence of the cloud. Many such investigations have been conducted in the Soviet Union as well as abroad [17-21]. Results of these investigations show that the particles forming these clouds have dimensions on the order of 10^{-5} cm. This value was obtained for various appearances and independent assumptions on the material composition of the particles, i.e. whether they were the products of sublimation of water vapor at m = 1.33 or of mineral dust particles (SiO_2) with m = 1.55. Table 1 shows more precise results on the measurement of particles obtained through polarization.

TABLE 1

Effective particle radius, cm		Authors
[illegible]	[illegible]	
[illegible]	[illegible]	Witt
[illegible]	1.07·10^{-5}	Ch.I.Willmann
1.44·10^{-5}	1.23·10^{-5}	"
1.47·10^{-5}	—	"
1.5·10^{-5}	—	O.B.Vasil'yev

It should be noted that the attempts to observe the effect of a change in dimensions in the particles during an appearance have yielded no accurate results [18]. This permits us to make the conclusion that the particles forming the noctilucent clouds have during the time of their existence remained basically unchanged or that such a change was below the limits of accuracy for the method used. A third variation is also possible: if the dimensions of the particles increases as a result of sublimation of water vapor around a solid nucleus (green), this would result in no noticeable change in polarization because the effective refractive index would decrease and a change in the particle dimension would be impossible to observe. /18

Along with this there are the references by O. B. Vasil'yev to the fact that, using polarization observations, he succeeded in observing changes in the dimensions of particles with the course of time [20]. Taking into account the small number of such observations, this fact cannot be considered as firmly established; however, if we take into account that the particles are formed on the spot as a result of the sublimation of water vapor, it is natural to assume that there is such a change in the dimensions of the particles.

Photometric observation also lead to the same results concerning the dimensions of the particles. Ch.I. Willmann has determined the light scattering index for noctilucent clouds [19]. The indicatrix obtained from observations was compared with the theoretical indicatrices of weakly refracted particles. The best agreement was obtained with an indicatrix for particles m $(\frac{2\pi r}{\lambda})$ = 1.6 (r equals the particle radius and λ equals the wavelength). This means that in the given case the order of value for the particle dimension is reached in the same way as in polarimetric investigations. Thus, optical methods yield a more or less identical answer concerning the particle dimensions, but the question remains open as to the material content of these particles, and this question is vital for the understanding of their nature and the causes and dynamics of noctilucent cloud formations. Therefore, rocket investigations could substantially complement and develop the solutions to this question.

Such experiments were conducted jointly by researchers in Switzerland and the USA [22]. They succeeded in achieving the launch of the Nike-Cajun Rocket with the necessary equipment into a field of noctilucent clouds. This experiment was conducted on 11 August 1962 at the Swiss Launch Site of Kronogard. The noctilucent clouds on this night were observed by several ground stations in Switzerland. An identical experiment was conducted earlier -- 7 August 1962 -- at the same base, but without noctilucent clouds.

The experiments were carefully prepared and thought out. The apparatus for picking up the probes functioned only on the ascending phase of the trajectory and at an approximate altitude of 75 to 98 km. To eliminate possible side admixtures which might have remained in the containers during their laboratory preparation or which might have diffused therein during the rocket flight, one similar container was not opened in the clouds and served as control during processing of the probes obtained by the other container. Processing of the probes was done with a mass-spectrometer, an electromicroscope and other laboratory means.

On the basis of the results of analysis of the experiments conducted, which have been described in greater detail in [22-28], we may make the follow- /19
ing conclusions: 1) the nuclei of the particles making up the noctilucent clouds are of extra terrestrial origin; 2) the distribution of these nuclei in terms of dimensions follows the exponential law $N = Ad^{-p}$, where $3 < p < 4$; 3) the lower limit for the distribution of nuclei according to dimensions is rather clearly cut off around $5 \cdot 10^{-6}$ cm; 4) a substantial number of particles collected were covered with ice when captured; 5) the number of particles caught during flight in the noctilucent clouds was 10^3 greater than the number obtained where there were no noctilucent clouds; 6) the concentration of particles along a vertical column in the field of the noctilucent clouds was greater than $8 \cdot 10^{10}$ particles per 1 m^2; and 7) if we take into account that the volume density of the particles decreases exponentially with altitude, the thickness of the cloud field during the experiment was equal to approximately 2 km.

Very interesting results were also obtained in the study of the chemical composition of the particles obtained. It was found that they are basically composed of Fe and Ni with the Ni/Fe ratio equal to ~ 0.15. In addition, several particles had Fe and Si, Si and Ca in their compositions; particles were also found which consisted solely of Fe or Si. As can be seen, these particles are closer in chemical composition to meteoric materials (such as kamicite, tanite and Schreibersite) than dust particles of terrestrial origin.

The data confirming the existence of water in noctilucent clouds are quite valuable for clarifying the question of the origin of these clouds. An experiment especially arranged with this object has shown that during the flight through the cloud field, for each 1 cm^2 of probed surface, $1.5 \cdot 10^{-6}$ g water were collected. If we take into account the fact that $4.5 \cdot 10^4$ ice-covered particles were recorded per 1 cm^2, approximately $3 \cdot 10^{-12}$ g water can be attributed to each such particle.

The volume density and effective thickness of the various components of the noctilucent cloud field. Through absolute photometry, several authors have determined the absolute brightness of various features of the cloud field [19, 20, 29 and 30]. Table 2 gives the results for the determination of various appearances.

TABLE 2

Date of Appearance	Determined brightness	Interval of scattering angles	Authors
1 Aug 1957	[illegible] + $5.0 \cdot 10^{-6}$	[illegible]	O.B.Vasil'yev
[illegible]/16 Jul 1959	$0.9 \cdot 10^{-6} + 22.8 \cdot 10^{-6}$	—	V.V.Sharanov
15/16 Jul 1959	$1.1 \cdot 10^{-6} + 28.0 \cdot 10^{-6}$	21—29	Ch.I.Willmann
8/9 Jul 1961	$2.4 \cdot 10^{-11} + 9.6 \cdot 10^{-11}$	86—90	"
7/8 Jul 1961	$2.2 \cdot 10^{-9} + 3.4 \cdot 10^{-9}$	19—28	"

Note. Brightness is expressed in solar units, i.e. it is the brightness of an absolutely white screen positioned normally with respect to solar rays on the edge of the earth's atmosphere.

As can be seen from the data presented, the brightness of noctilucent clouds varies within a rather broad range as a function of the intensity of the cloud field for the given appearance and the scattering angle for a given point whose brightness has been determined. In all probability, such a variation of brightness is primarily conditioned by the concentration of particles, which might vary for different appearances. We may also assume that the effective thickness of the cloud layer is not constant for different appearances and, of course, differs for different structural shapes in the cloud field. However, changes in the cloud thickness to such a degree as might yield a variation in brightness of the fifth or sixth order are very improbable. It is also scarcely possible to consider the variation in the particle dimensions for various appearances as the chief cause of such a wide range in brightness changes. /20

Judging according to the shape of the indicatrices obtained, the brightness of a given feature in the cloud field may vary as a function of the scattering angle (for $0° \leq \theta \leq 90°$) only within the limits of two orders of value.

In the final analysis, the brightness of noctilucent clouds is a function of all the factors stated above. These factors (with the exception of the scattering angle), in turn, are functions of the physical conditions for the formation (accumulation or formation) of aerosols constituting the noctilucent clouds. Thus, the results in the determination of the brightness of noctilucent clouds may yield valuable data concerning their physical nature as well as the mechanism of formation.

Such attempts have in fact been made. The volume density of particles constituting noctilucent clouds and the effective thickness of the various structural shapes for the cloud field have been determined. Tables 3 and 4 present some results.

TABLE 3

Mean particle concentration, cm^{-3}	Method of determination	Authors
$4\cdot10^{1}$	Rocket studies	Witt, et al [22]
10^{-1} for $r = 10^{-4}$; [illegible] for $r = 10^{-6}$; [illegible] for [illegible] and $r = 10^{-5}$	Theoretical investigations	Ludlam [32]
[illegible] for [illegible] and $r = 10^{-5}$	Photometric studies	Ch. I. Willmann [19]
[illegible] for $r =$ [illegible]	Photometric studies	O. B. Vasil'uev [20]
[illegible] $- 3\cdot10^{-3}$ for $r = 10^{-4}$; [illegible] $- 3\cdot10^{-1}$ for $r = 10^{-5}$; [illegible] $10^{-1} - 3\cdot10^{1}$ for $r = 10^{-6}$	Theoretical calculations	V. A. Bronshten [33]

TABLE 4

Structural Shape of cloud field	Effective vertical thickness of layer relative to earth's surface, km	
	$m = 1.33$	$m = 1.55$
Crape	0.13	0.18
Weak crest	0.40	0.45
Sharp crest	1.52	1.70
Vortex	2.02	2.25
Vortex core	3.60	4.00

The values given in Table 4 were obtained by Ch. I. Willmann [19] photometrically from the appearance of noctilucent clouds on 15/16 July 1959 and were proven indirectly. To this end, the formula

$$N = \frac{b_0 - b_S}{b_S} \frac{\gamma}{4\pi} \frac{\alpha_\mu}{\alpha_N} n,$$

was developed, where b_0 is the measured total brightness of a given point, /21
b_S is the brightness of the twilight sky at the same spot without noctilucent clouds, γ is the proposed solid angle in which direction the basic flow of the particles of scattered light are directed, α_N and α_μ are the light scattering coefficients for the cloud particles and air molecules respectively, n is the number of air molecules per unit volume and N is the number of particles for noctilucent clouds of a given diameter in the same volume. The number n is determined by integration of the density function according to a standard atmosphere within the limits from 70 to 700 km over the earth's surface. The calculated particle concentration and effective thickness of the various structural shapes were obtained for the same order as was shown in Tables 3 and 4 respectively.

In summer of 1964 in Alaska (ϕ = 64.9° N and λ = 148.1° W), Orlando Skags Bay (ϕ = 56.6° N and λ = 16.5° E) and Torsta (ϕ = 63.3° N and λ = 14.5° E) Fiocco, Grams, Urbanek and Breeding conducted sounding of the mesophere (from 52 to 100 km) with an optical laser (λ = 6943 A). The soundings were conducted several times simultaneously with the appearance of noctilucent clouds [31]. Although these clouds were observed visually over the northern horizon (several hundred kilometers from the sounding points) and the soundings were carried out in the zenith, it was nevertheless possible to assume that the heaviest layer, from which the laser beam was reflected, was at a level of altitude around 80 km. However, actually the most powerful signals were obtained from the layer located at around 70 km. Then on 16/17 August in Torsta, in the presence of noctilucent clouds, signals were obtained from the layer at 80-88 km, these signals being more powerful than those reflected from other altitudes. In this case, the optical thickness of the 80-88 km layer appeared to be equal to $4 \cdot 10^{-5}$. This value exceeds the value determined by Ludlum in [32] ($2 \cdot 10^{-6}$), but corresponds sufficiently well with the values obtained by Willmann ($2.4 \cdot 10^{-5}$) from photometric observations of noctilucent clouds during the appearance of 15/16 July 1959. The mean values for the optical thickness of the layer located at an altitude of approximately 80 km was equal to $(1.0 \pm 0.2) \cdot 10^{-5}$ for all the laser determinations, when the noctilucent clouds were observed visually.

This was the first attempt to use laser technology to study noctilucent clouds. In all probability, such a method will be useful in future investigations of noctilucent clouds, especially at solar altitudes, when these clouds cannot be observed visually.

The altitude, kinematic characteristics and dynamics of the noctilucent cloud field. The questions discussed are some of the most challenging in terms of using the results of studies of noctilucent clouds for studying the upper layers of the atmosphere. The multiform morphological structure of the cloud field and its changes permits us to track the complex dynamic processes (wave motions, structural flows and turbulence) occurring in the mesopause. When compared with other means, this method of studying various types of motion in the noctilucent cloud field has a substantial advantage, namely that noctilucent clouds occupy an area of several thousand and sometimes million square kilometers and are visible for hours. This permits tracking the dynamic processes in the mesopause for a rather long while and at the same time over broad areas.

Nor is the study of various types of motion in a noctilucent cloud field limited only to the study of the dynamics of the mesopause, but in all probability also permits the interpretation of various phenomena occurring in the ionosphere and the study of questions related to turbulence in the upper layers as well as an understanding of the dynamics of the upper layers in general.

To study the dynamics (especially wave motions) of a noctilucent cloud field, we need information on the height and kinematic character of these clouds, as well as data on the wind and temperature in the mesopause. The first of these may be obtained from base observations, aerophotogrammetry and slow-motion pictures. Aerial photogrammetry has already been used several times and has yielded very valuable information both on the altitude of the noctilucent clouds and for study of the wind in the mesopause (see, for example, the article by M. I. Burov in this collection). No less important are the works by N. I. Grishen in the study of wave motions of noctilucent clouds through slow-motion films from a single point [34]. We plan the future use of both of these methods and the basic slow-motion photographing of noctilucent clouds. /22

The equidensitometric method discussed in [35] may also be used in the study of various types of motion in the cloud fields. The study of isodensitograms obtained from many sequential photographs of noctilucent clouds yields information on the shifting of cloud masses in the cloud fields.

Along with the accumulation of factual data on the kinematic characteristics of noctilucent clouds and the wind and temperature in the mesopause, it is desirable to conduct theoretical works as well on questions relating to the dynamics of the noctilucent cloud field. There have been few such works to date. Haurwitz [36] has considered several problems concerning the wave motions of noctilucent clouds. In his work, the waves for these clouds were interpreted as gravitational.

The work of the Special World Geophysical Center (SWGC; Russ, MSGTs) on noctilucent clouds. The SWGC on noctilucent clouds was created in 1964 at the V. Ya. Struve Institute of Physics and Astronomy of the Academy of Sciences of the Estonian SSR in Tartu [37]. The Center's task was the methodological control of all stations taking part in the patrol observations of noctilucent clouds, the collection and pre-processing of observations data received from these stations and the exchange of data through the World Data Center.

For 1964, the SWGC obtained a total of 1489 logs of observations (type I-SO-IQSY - International Year of the Quiet Sun) from 202 stations throughout the territory of the USSR which were carrying on patrols in accordance with a standard program from 1 March to 1 November [38]. The nature of these observations was that during the intermediate and dark phases of twilight, the observer would carefully scan the sky every 15 minutes with the object of establishing the presence or absence of noctilucent clouds and recording the state of the overall cloud cover. The observations are carried on under any meteorological conditions.

The preliminary processing of visual patrol observations consists of the careful evaluation of the records from the monthly logs compiled by the observation stations and the compilation of general data in decades for each station according to the international form F-1-S and for each appearance of noctilucent clouds according to form F-2-S.

Bearing in mind that the material obtained would undergo more detailed future analysis to study the time-space characteristics of the appearances of noctilucent clouds, and that a rather large amount of observational material would be received, a file of punched cards containing observational data was established at the SWGC. Two versions of these cards were foreseen: a) those containing the punched total data for each individual observation day for each individual station according to the log entries on the form 1-SO-IQSY; and b) those on which detailed data concerning each individual case of the appearance of noctilucent clouds are punched. The file for this type information will consist of approximately 50,000 cards for one observation period for the USSR stations.

With respect to the switch to full automation of processing visual patrol observations of noctilucent clouds, the SWGC recording the indicated observations in 1965 at stations in the Soviet Union will be conducted through the loading of marked punched cards. Such a recording system and the corresponding punched card code will aid in the future fully automated processing of observational data through the use of a reading keypunch machine and computer. /23

The marked punched card in fact amounts to a questionnaire which demands simply a "yes" or "no" answer to each of its questions. Each oval on the punched card is one such elementary question (Figure 4). A "yes" answer to a given question will be marked by penciling in the corresponding oval, with the un-darkened oval representing a "no" answer. This method of "data entry" is very convenient for the observer as well.

Table 5 shows the number of appearances of noctilucent clouds recorded by GUGMS (State Ministry of the Hydrometeorological Service) stations throughout the USSR in 1964.

More detailed results in the patrol observations for 1964 will be published individually after the observational material obtained have been fully processed.

The data from the stations in other countries around the world have been only partially represented because at present full analysis on a global scale is not yet possible.

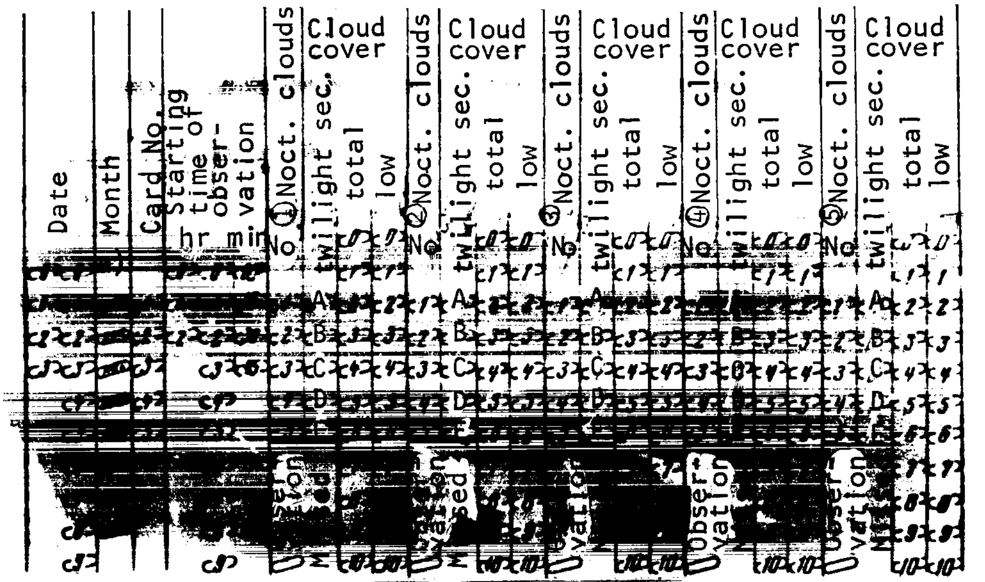

Figure 4. A Marked Punched Card for Recording Visual Patrol Observations of Noctilucent Clouds. KEY: a) Mar., Apr., May, June, July, Aug., Sept., Oct.

TABLE 5

	Mar.	April	May	June	July	Aug.	Sept.	Oct.	TOTAL
Number of appearances. . .	1	11	13	39	83	29	14	7	197
Number of stations picking up noctilucent clouds	1	10	9	26	38	16	11	7	118
Number of nights noctilucent clouds observed.	1	10	12	19	24	17	10	7	100

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